AD-A121 618 IMPACT BEHAVIOR OF FIBROUS COMPOSITES AND METAL SUBSTRUCTURES(U) ARMY AVIATION RESEARCH AND DEVELOPMENT COMMAND ST LOUIS MO A J GUSTAFSON ET AL. OCT 82 1/1

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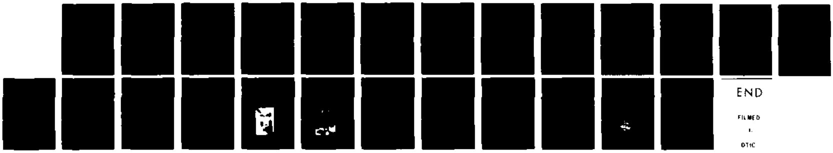

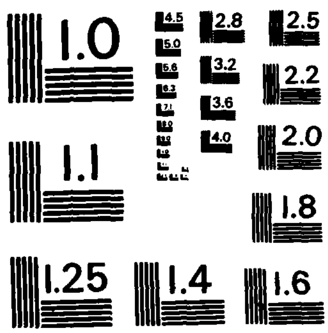

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IMPACT BEHAVIOR OF FIBROUS COMPOSITES AND METAL SUBSTRUCTURES

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October 1982

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER USAAVRADCOM TR 82-D-31	2. GOVT ACCESSION NO. AD-A121	3. RECIPIENT'S CATALOG NUMBER 618
4. TITLE (and Subtitle) IMPACT BEHAVIOR OF FIBROUS COMPOSITES AND METAL SUBSTRUCTURES		5. TYPE OF REPORT & PERIOD COVERED 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) A. J. Gustafson G. Shek Ng G. T. Singley, III		8. CONTRACT OR GRANT NUMBER(s) House Task 75-30
9. PERFORMING ORGANIZATION NAME AND ADDRESS Applied Technology Laboratory, US Army Research and Technology Laboratories (AVRADCOM) Fort Eustis, Virginia 23604		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 1L262209AH7602B
11. CONTROLLING OFFICE NAME AND ADDRESS		12. REPORT DATE October 1982 13. NUMBER OF PAGES 23
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Composite substructures
Metal substructures
Load-deflection curves
Impact behavior
Energy absorption

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This program was conducted to determine the differences in nonlinear load-deflection characteristics between a typical helicopter ventral substructure fabricated with aluminum and one designed to the same loads criteria fabricated with fiber composite materials. The feasibility of applying the analytical and testing techniques developed under contract for a metal structure to a composite structure was investigated. The composite structure was designed as a one-for-one replacement of the metal structure to meet the same design loads that were used for the metal structure. Because full-scale specimen testing could not be performed using existing in-house equipment, a scale model

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test was conducted. A dimensional analysis procedure based on the scaling laws of the Buckingham theorem was used to define the scaling approach. The feasibility of testing scaled helicopters for proofing crash survivability requirements was also examined. Test results obtained were in agreement with those reported under the contractual effort and demonstrated that fuselage structures can be scaled for impact testing. The composite structure showed slightly lower energy absorption than the metal structure.

PREFACE

The authors wish to acknowledge the contributions of the following individuals without whose help the work reported herein could not have been accomplished: Lacy D. Bartlett, Edward L. Young, Ronald G. Bott, Alan M. Williamson, Patrick A. Hedges, Louis R. Bartek, and Bernard L. Karp.

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INTRODUCTION

PHASE I

In Phase I of this program the feasibility of testing scaled fuselage structures for crash-energy absorption potential was examined. Although scaled automobile and railroad structures have been successfully tested,[1,2] there were no reports on scaled aircraft fuselage testing. The scale modeling concept was tested by repeating the peak failure load and specific energy absorption tests performed by Lockheed-California Company on one-half-size specimens and comparing the results, properly scaled, to those reported in Reference 3.

The all-metal test specimens of Reference 3 were approximately one-half-scale models of a typical UH-1D helicopter pylon support structure located between fuselage stations 102 and 160 just aft of the landing gear, as shown in Figure 1. A schematic of the Lockheed test specimen is shown in Figure 2. The pylon support structure consists of inner and outer skins representative of the cabin or cockpit floor and the helicopter lower fuselage skin, respectively, connected by a series of beams running aft and by bulkheads. During helicopter accidents, this structure is the means by which the vertical ground impact forces are transmitted to the transmission. In order to maintain a livable space in the cabin during a helicopter crash, the structure surrounding the cabin must remain intact and prevent large mass items such as the transmission from breaking loose and entering the cabin. The failure mode, the amount of energy absorbed, and the pulse shape produced are therefore of interest in assessing the crashworthiness of a helicopter.

PHASE II

In Phase II the specific energy absorption of an all-composite structure was compared to that of a metal structure. The composite structure was designed to meet the same operational loads as the metal structure tested in Phase I. This test specimen is shown in Figure 3. Because of the interest in composite airframe structures for future aircraft, it is important to investigate the characteristics of typical composite structures with respect to their performance during crash impact loading.

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[1] M. J. Pavlick, *Development of Energy Absorbing Automotive Structures Using Scale Model Test Techniques*, Report 740570, The Budd Company.

[2] B. S. Holmes and G. Sliter, *Scale Modeling of Vehicle Crashes - Techniques, Applicability, and Accuracy; Cost Effectiveness*, 1974 Occupant Restraint, Society of Automotive Engineers, Inc.

[3] G. Wittlin and K. C. Park, *Development and Experimental Verifications of Procedures to Determine Nonlinear Load-Deflection Characteristics of Helicopter Substructures Subjected to Crash Forces*, Lockheed-California Company, USAAMRDL TR 74-12A and B, Eustis Directorate, US Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia, May 1974, AD 784191 and AD 784192.

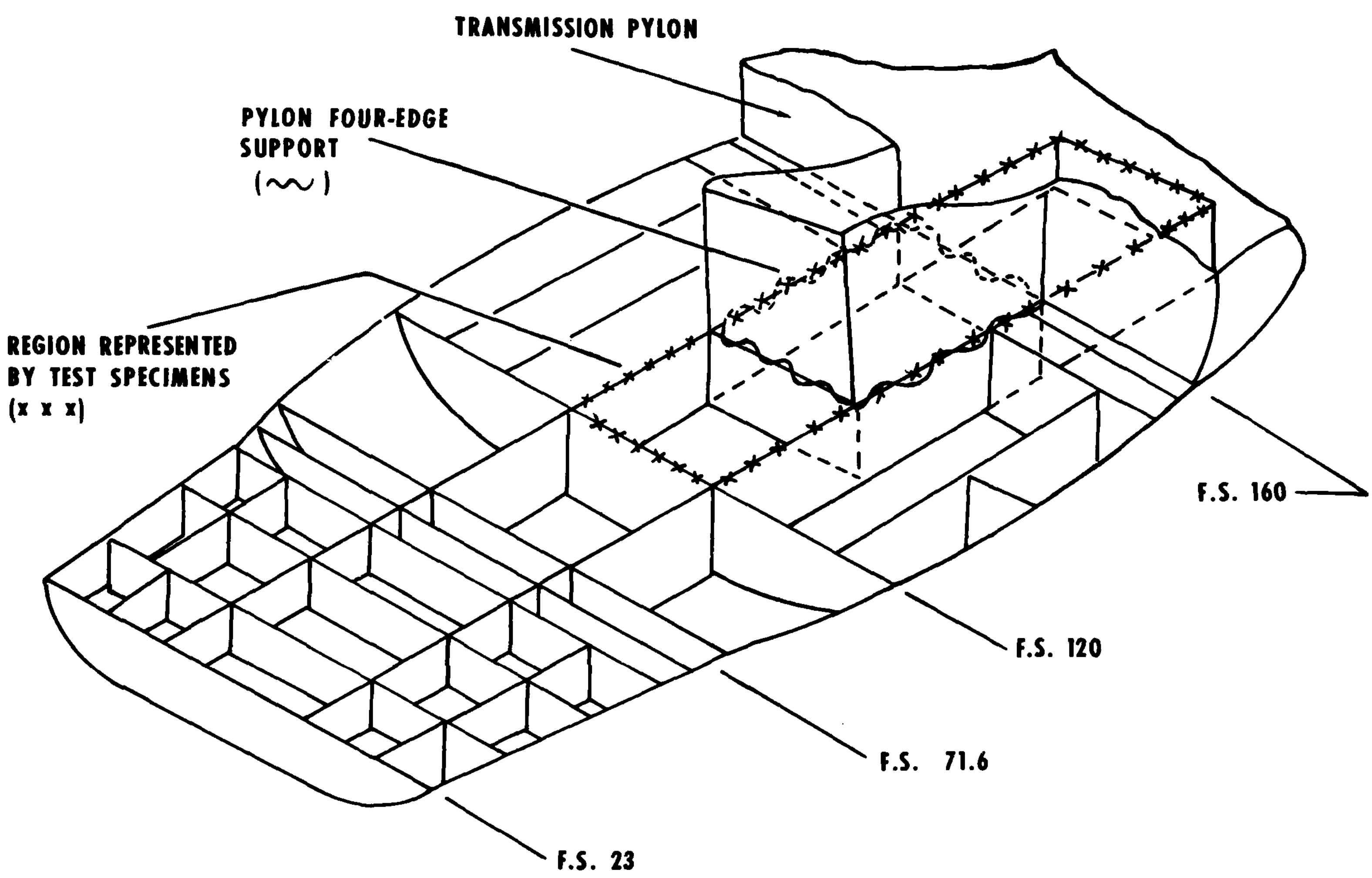


Figure 1. Fuselage region of UH-1D showing location duplicated by test specimen.

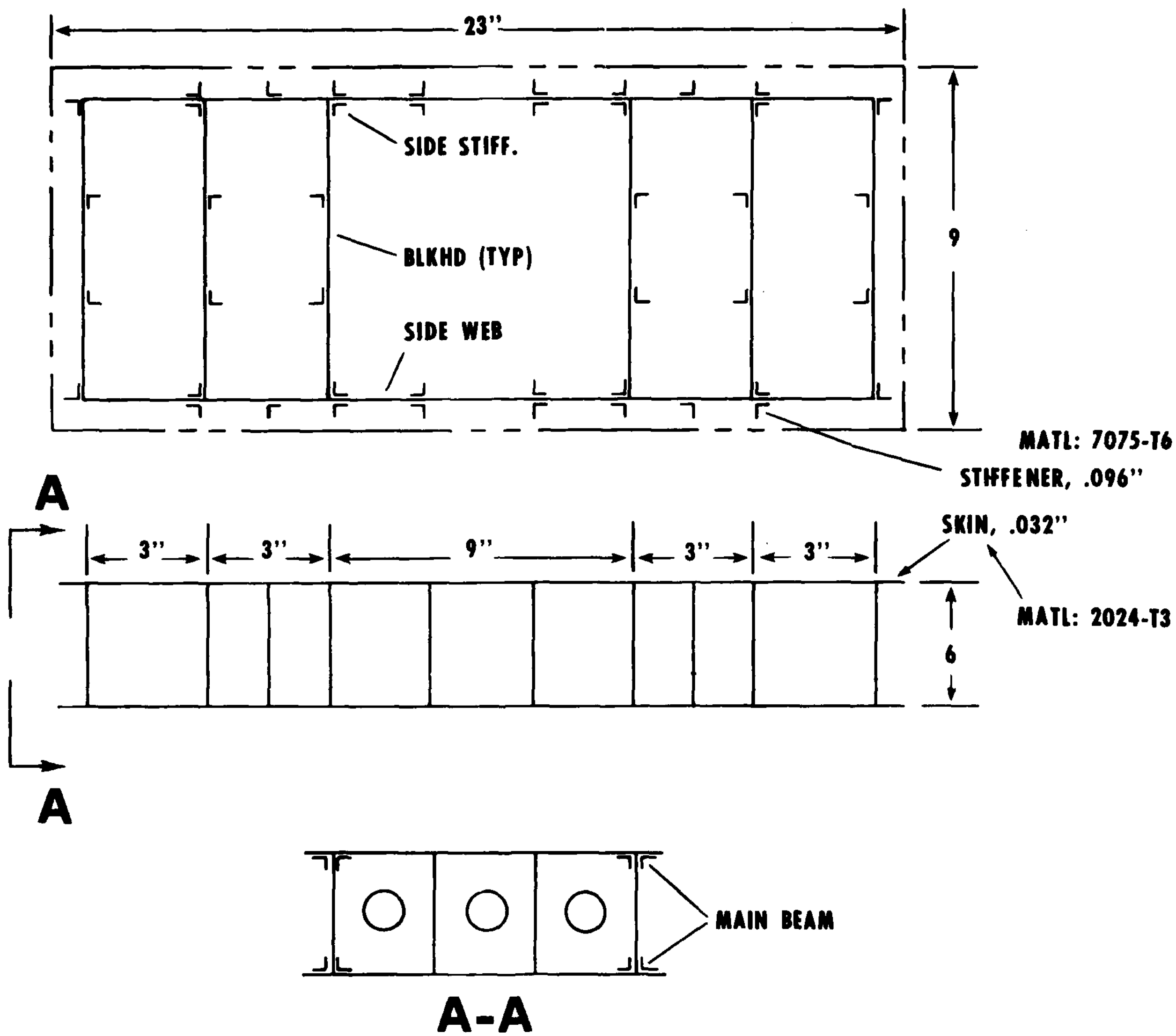


Figure 2. Aluminum skin-stiffener structure.

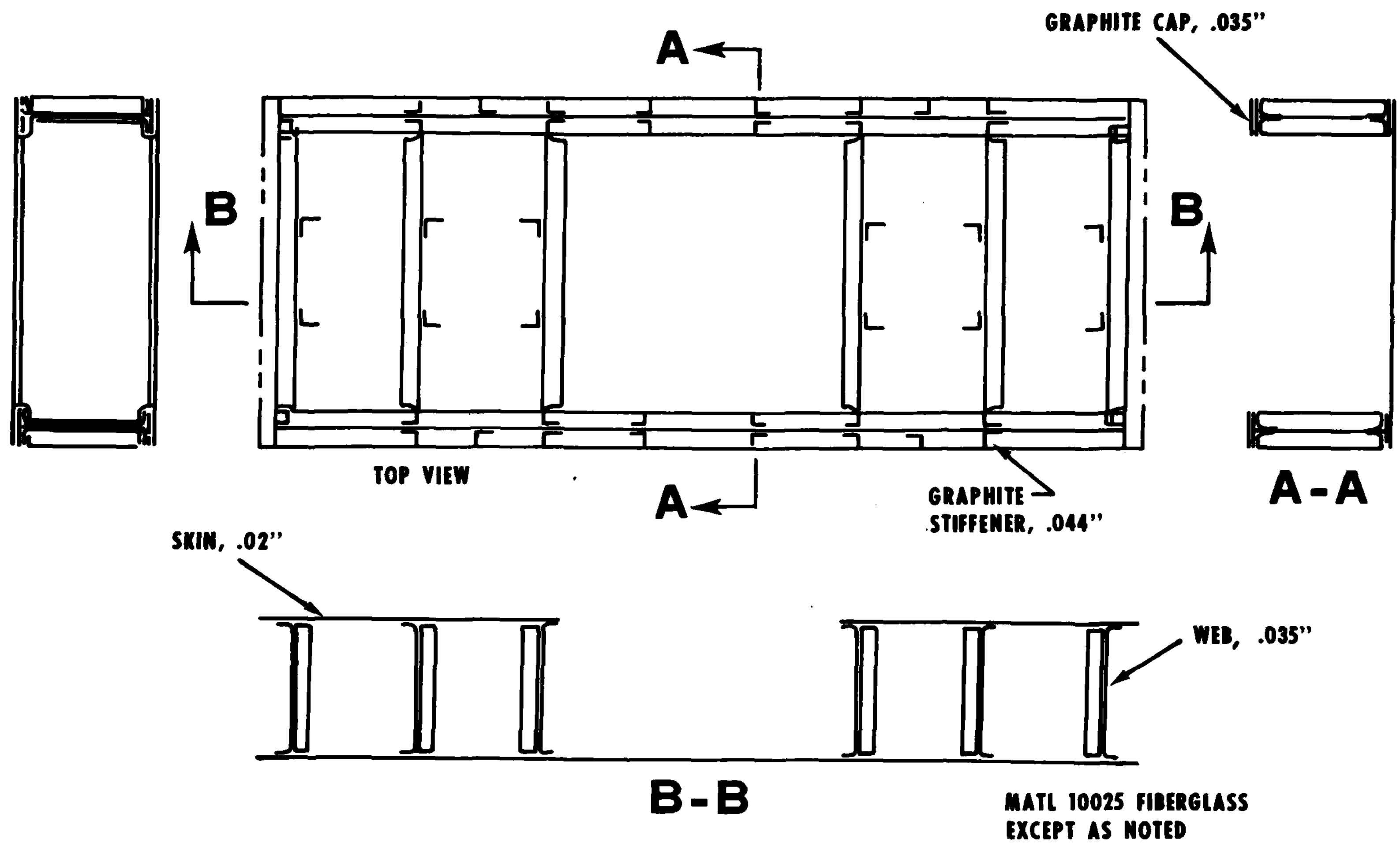


Figure 3. Composite skin structure — one-for-one design.

SPECIMEN DESIGN

Both the aluminum skin-stringer and the composite specimens were designed to meet the flight limit load condition defined in Reference 3 as condition II, symmetrical pullout. These design loads are graphically represented in Figure 4. The ultimate strengths of the metal and the composite specimens are not the same for all loading conditions due to the differences in material properties. Equality is obtained only for the most critical design load conditions. This does not represent a serious limitation in comparing energy absorption per unit weight of the two designs.

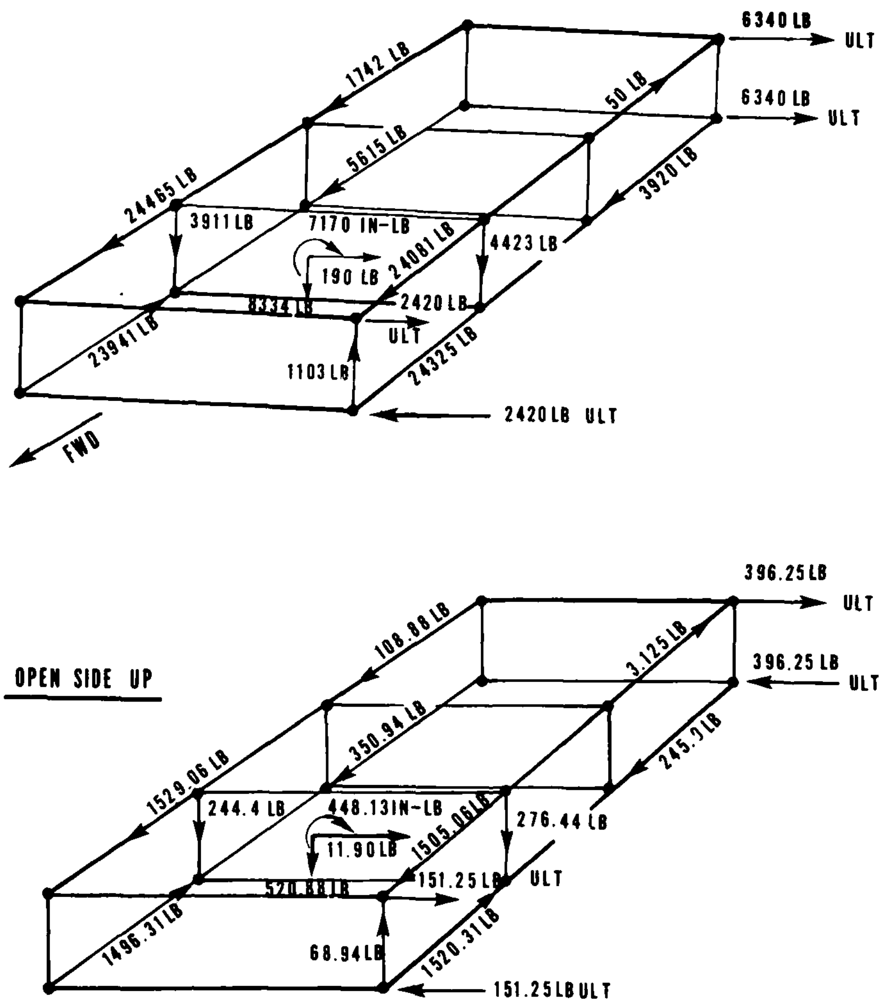


Figure 4. Schematic of UH-1B helicopter substructure showing scaled design loads.

DIMENSIONAL ANALYSIS

The original reason for using a scale model was to allow use of the existing in-house test facilities. Therefore, the possibility of reducing the cost of specimen fabrication and testing was carefully examined. The first scaling parameters chosen were identical to those described in Reference 1 because the scaling factors derived in that study had been successfully applied to a number of structural design configurations. The variables of interest and their scale factors are listed in Table 1.

TABLE 1. FIRST SET OF PARAMETERS CONSIDERED FOR DIMENSIONAL ANALYSIS

Parameter	Model Scale Factor*
v, velocity	unity
t, time	S
m, mass	$1/S^3$
ℓ, length	S
ρ, material density	unity
σ_Y, material yield stress	unity
C, strain rate coefficient	S
a, acceleration	1/S
E, modulus of elasticity	unity
F, force	S^2

*S = 1/2

The only problem in scaling the substructure was the selection of rivet size. Scaling is allowed for rivet diameter or cross-sectional area. There is no a priori reason for selecting either parameter. In this study, the diameter was selected for scaling so that the failure mode of the scaled structure would be the same as that of the full-scale structure. The failure mode of rivets, shearing versus sheet crushing, is a function of spacing and the ratio of rivet diameter to sheet thickness. These relations are preserved if the diameter is scaled. Other applications may require that the rivet ultimate strength be the critical parameter, in which case the rivet area would be the parameter to be scaled.

The variables selected in Reference 1, however, do not include all factors that are of interest in crash-impact testing of helicopters. Acceleration due to gravity, aspect ratio, energy, and moment of inertia are some of the additional variables to be considered. To study these variables, a new set of dimensionless products was calculated using Buckingham's theorem.

The new set of variables and their scale factors are listed in Table 2. The material properties considered were those relevant to material performance with high loading rates. The dynamic properties considered were those relevant to the application of the techniques described in Reference 3. The dimensionless products derived from these variables are listed in Table 3 along with the scale factors derived from these products. Scale factors were derived by applying the following rules: (1) Length is the primary value to be scaled, and (2) material, and therefore material properties, will be kept the same. The resulting scale factors are consistent with those derived in Reference 1.

It should be noted that the effects from acceleration due to gravity have to be scaled. This result was also found by Holmes and Sliter in Reference 2. The significance of this requirement is that this variable cannot be scaled practically in crash testing. Therefore, for those tests which involve vehicle rebound or significant body forces, or where structural vibration is important, the scaled test would not be representative of the effects that would be produced on the full-scale structure from the same type of test. For crash impact of helicopters, all of these factors are important if the crash forces are generated by the test object falling under the influence of gravity, such as in a pendulum-type test. Since large body forces will develop from the inertia of the rotor system and the transmission, this variable is particularly important and its contribution to impact dynamics may be significant.

TABLE 2. SECOND SET OF PARAMETERS USED FOR DIMENSIONAL ANALYSIS

Parameter	Model Scale Factor*
Material Related	
ρ, material density	unity
σ_y, material yield stress	unity
σ_μ, ultimate stress	unity
C, strain rate coefficient	1/S
E, modulus of elasticity	unity
μ, Poisson's ratio	unity
Dynamical Related	
ϵ, energy	S^3
ℓ/d, aspect ratio	unity
g, acceleration due to gravity	1/S
a, acceleration	1/S
I, moment of inertia	S^4
$\dot{\epsilon}$, strain rate	1/S
ℓ, length	S
x, general coordinate	S
τ, time	S
F, force	S^2
v, velocity	unity
m, mass	S^3

*S = 1/2

TABLE 3. DIMENSIONLESS PRODUCTS FOR SECOND SET OF PARAMETERS USED FOR DIMENSIONAL ANALYSIS

$\pi_1 = E/\sigma_Y$	$\pi_9 = \ell a/\sigma_\mu^2$
$\pi_2 = \epsilon_\mu$	$\pi_{10} = t\sigma/\ell$
$\pi_3 = \mu$	$\pi_{11} = I/\ell^4$
$\pi_4 = \rho v^2/\sigma_\mu$	$\pi_{12} = F/\sigma_\mu \ell^2$
$\pi_5 = x/\ell$	$\pi_{13} = mv^2/\sigma_\mu \ell$
$\pi_6 = E/\sigma_\mu \ell^3$	$\pi_{14} = \ell\dot{\epsilon}/\sigma_\mu$
$\pi_7 = \ell/d$	$\pi_{15} = \ell C/\sigma_\mu$
$\pi_8 = \ell g/\sigma_\mu^2$	$\pi_{16} = mv^2/\sigma_\mu \ell^3$

TEST PROGRAM

STATIC TEST

Each specimen was mounted in the 100-kip MTS testing machine on the four-edge support shown in Figure 5. The anvil shown in Figure 5 was attached to the upper (fixed) head of the machine. A controlled constant deflection rate was applied. Initially, the rate was 0.05 inch per minute. After initial failure (buckling) was attained, the loading rate was increased to 2 inches per minute. Both load and deflection were plotted. Load was measured directly with a force transducer in the testing machine and the deflection was obtained using a linear variable differential transducer (LVDT).

The load deflection was plotted on a Moseley 2F3A X-Y plotter. Load time and deflection time were plotted on a Brush Model 280 recorder. The test specimen was instrumented with two strain gages (Micromeasurements Gage No. WK-06-250AF-350). Both measured compression and/or bending of the end beam. Still photographs of the test setup and the test specimen before and after testing were taken.

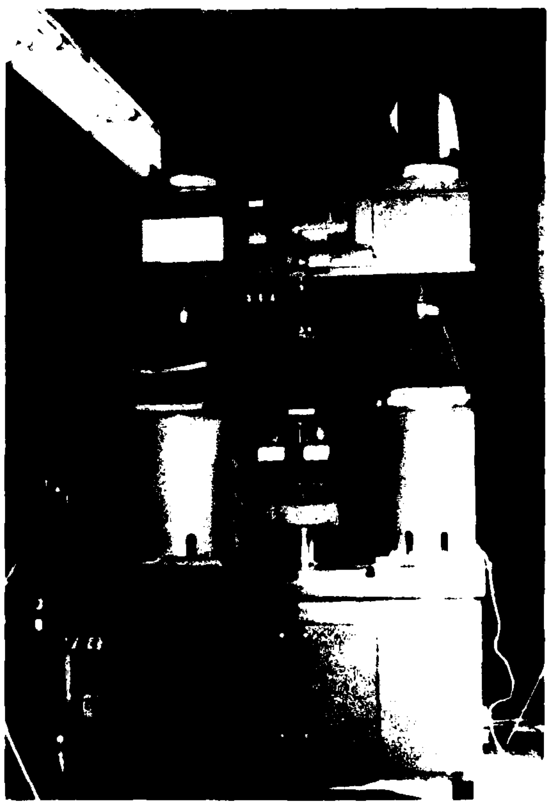


Figure 5. View of 100-kip load frame used for load-deflection tests.

DYNAMIC TESTS

The test specimens rested on the four-edge support that was positioned on the impact test machine base as shown in Figure 6. The anvil was attached to the impact head. Care was taken to assure that the planes of the anvil, specimen, four-edge support, and base were parallel to each other. After the specimen was mounted and the test setup checked, the impact anvil and mass were raised to the designated height (36.5 inches) and released. The specimen load-deflection data and the acceleration of the impact head were recorded during the dynamic testing.

Two vertically positioned Endevco 226 (piezoelectric) accelerometers (200G range with a frequency response of approximately 1600 Hz) were mounted on the impact head. This acceleration data yields specimen loading data. Dynamic test data were recorded on the IED 250 recorder.

High-speed (1000 and 2000 fps) motion picture coverage was employed and synchronized with the tape-recorded data. Cameras were placed at 45 and 90 degrees to the specimen longitudinal axis on opposite sides of the specimen.

Acceleration time histories were plotted for the raw accelerometer data and for 200-cycle-per-second low pass filtered data. The sampling rate was 3000 scans per second. Compressive strain was defined as positive for the strain gage data.

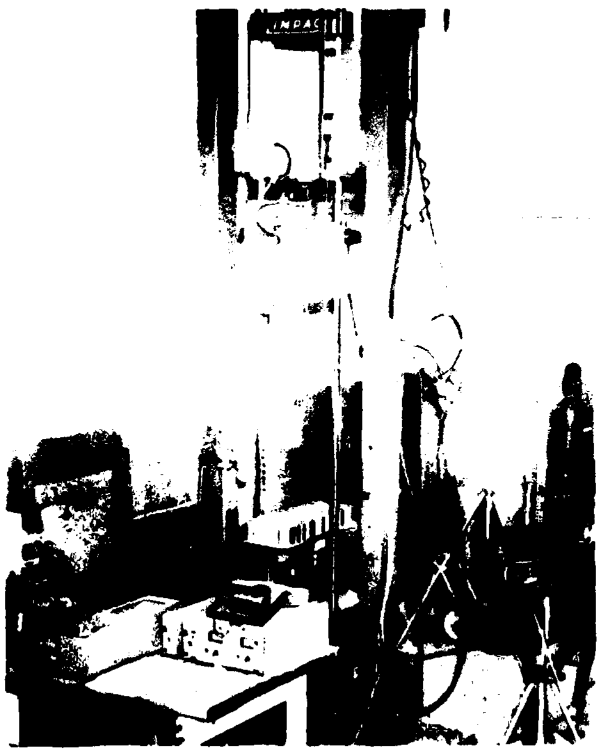


Figure 6. Composite specimen mounted in impact machine.

RESULTS

The results of the static tests are shown in Table 4, which compares calculated and measured test data.

Load-deflection curves for the one-half-scale metal specimen and the equivalent composite specimen are shown in Figures 7 and 8, respectively. Comparing the load-deflection curves of the two specimens shows that the one-half-scale aluminum specimen had higher peak loading but the specific energy absorptions were about equal.

The reduced impact data from the dynamic tests of the metal skin stringer and the composite specimens are given in Table 4. Figure 9 gives a typical trace of accelerometer output.

The average reaction load of the composite specimen during dynamic testing was slightly higher and of shorter duration than that of the skin-stringer specimen, which indicates that the metal specimens were better energy-absorbing structures in this test.

TABLE 4. COMPARISON OF CALCULATED AND MEASURED TEST DATA

Parameter	AL Skin-Stiffener (Baseline)		Composite Skin-Stiffener	
	Calculated	Measured	Calculated	Measured
Weight, lb	–	2.899	2.3559	2.728
EI, flex, lb-in.^{2} x 10^6	8.6436	–	8.206	–
EI, comp long, lb-in.^{2} x 10^6	8.6436	–	8.206	–
Max load, flex, lb	4,389.23	–	9,168.801	–
Max load, comp long, lb	3,495.68	–	2,740.50	–
Max load, comp trans, lb	1,572.00	–	1,552.95	–
Max load, comp test, lb	35,550.74	–	46,446.0	26,000.0
Max torsion, in.-lb	10,561.58	–	22,062.44	–
Deflection at 75 lb	0.00072	0.004	0.000697	0.005
Deflection at 125 lb	0.001234	0.006	0.00116	0.007
JG, flex, lb-in.^{2} x 10^6	29.488	–	32.359	–
JG, comp, lb-in.^{2} x 10^6	29.488	–	32.359	–
Margin of safety (MS), flex	1.8	–	3.89	–
MS, comp long	0.045	–	0.196	–
MS, comp trans	1.64	–	1.18	–
MS, torsion	1.1	–	3.4	–
Max g, impact test	–	50.0	–	65.9
Curve	–	Approx triangular	–	Approx triangular
Time base	–	15 ms	–	10 ms

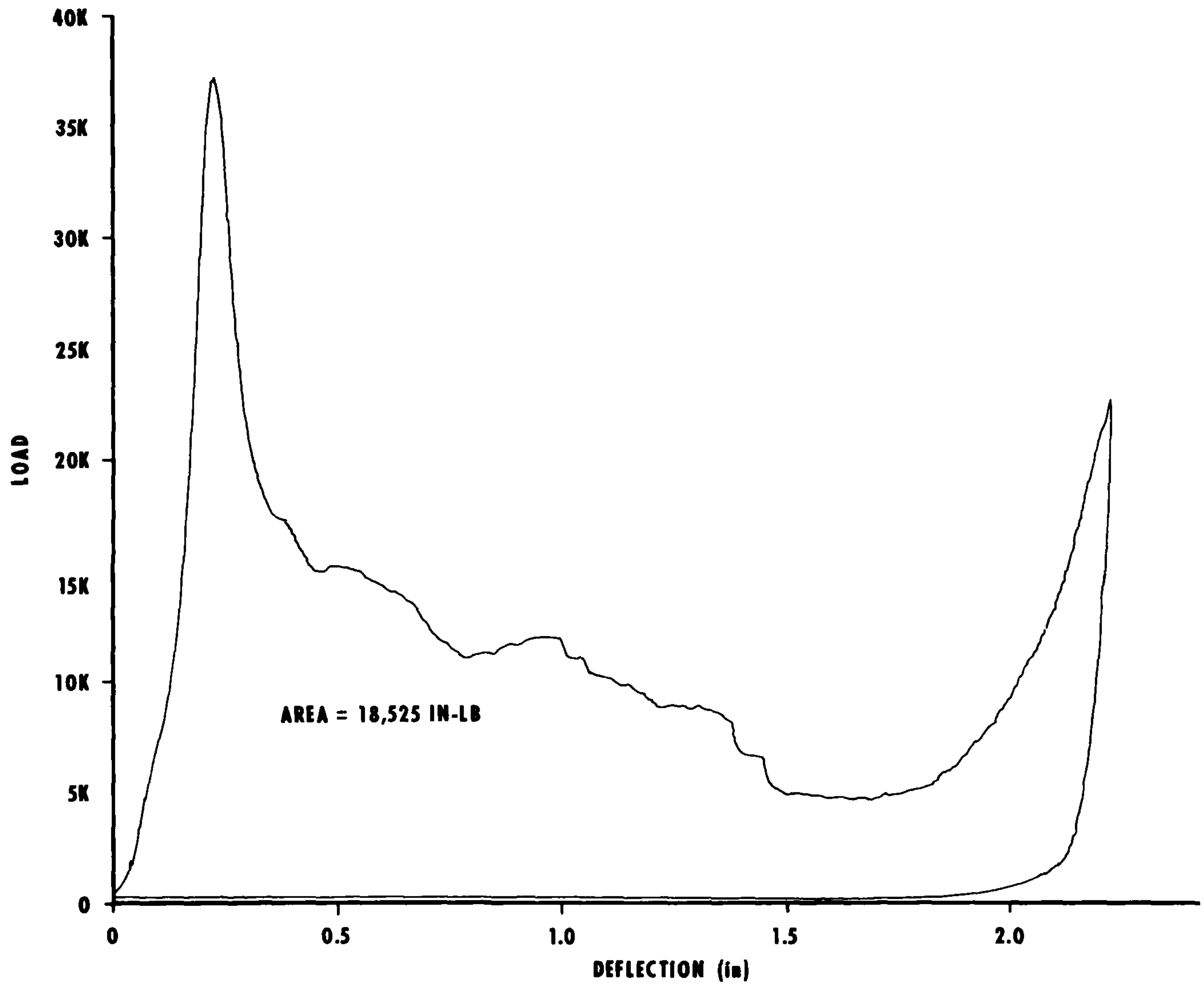


Figure 7. Load-deflection curve for the one-half-scale metal specimen.

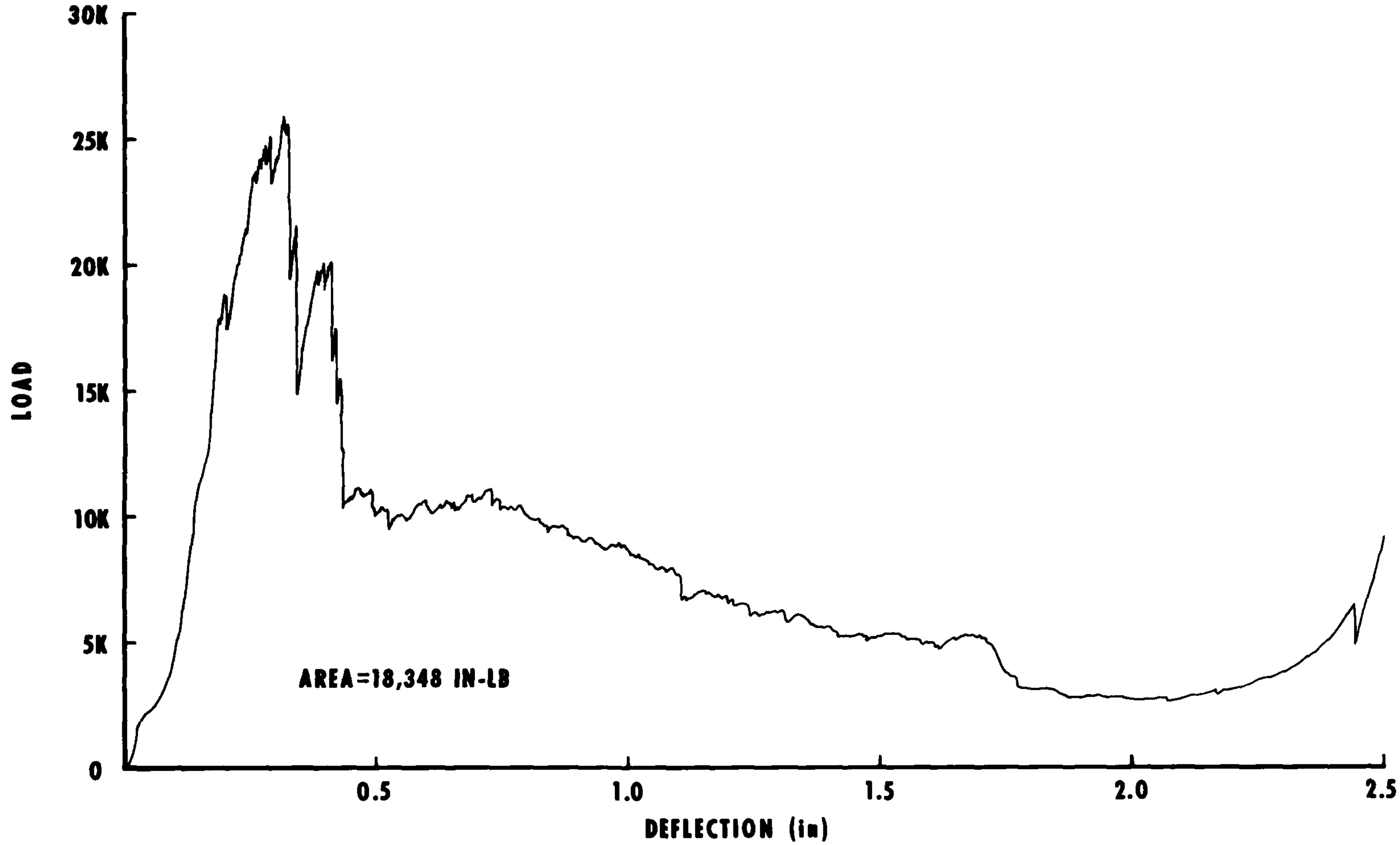
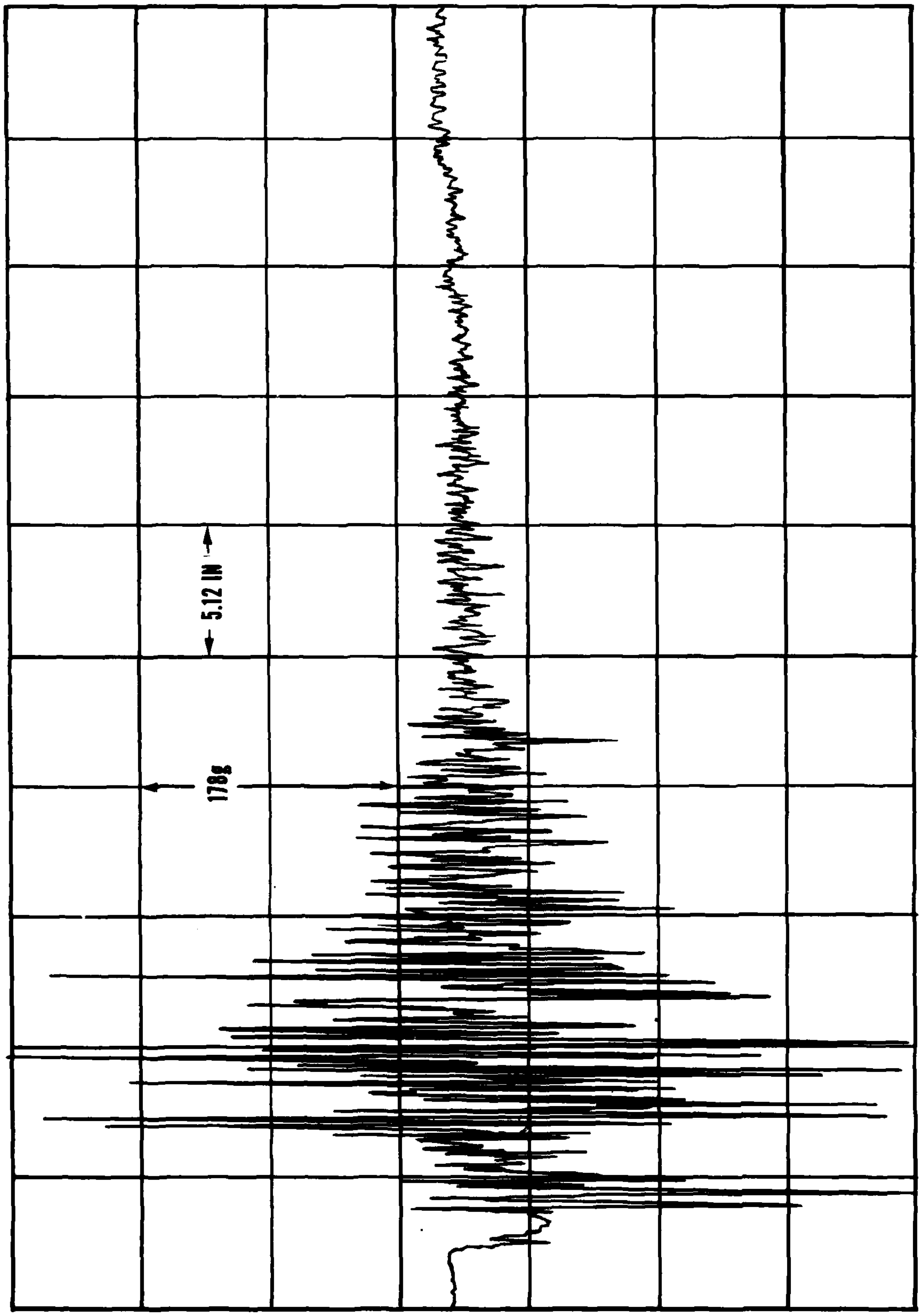


Figure 8. Load-deflection curve for the one-half-scale composite specimen.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CONCLUSIONS

1. The economic benefits of scaling fuselage structure are considered marginal because of increased labor costs.

2. Results from drop testing scaled fuselage structure cannot be fully translated to full-scale structure because the effects of gravity cannot be reasonably scaled.

3. The use of a static strength test to predict energy absorption on scaled metal fuselage structure is feasible.

4. Composite structures must be specially designed to obtain meaningful energy absorption, primarily due to the brittle nature of these materials. (This is consistent with results reported in Reference 4.)

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[4] J. D. Cronkite, T. J. Haas, V. L. Berry, and R. Winter, *Investigation of the Crash-Impact Characteristics of Advanced Airframe Structures*, Bell Helicopter Textron, USARTL TR 79-11, Applied Technology Laboratory, US Army Research and Technology Laboratories (AVRADCOM), Fort Eustis, Virginia, September 1979, AD A075163.

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